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AN OPERATIONAL COMPARISON OF THE CH-46E AND HH-60H AS NAVY COMBAT SUPPORT HELICOPTER REPLACEMENT OPTIONS USING THE SIMULATED MOBILITY MODELING AND ANALYSIS TOOLBOX (SMMAT)

by

Timothy M. Wilson
September 1994

Thesis Advisor: Michael P. Bailey

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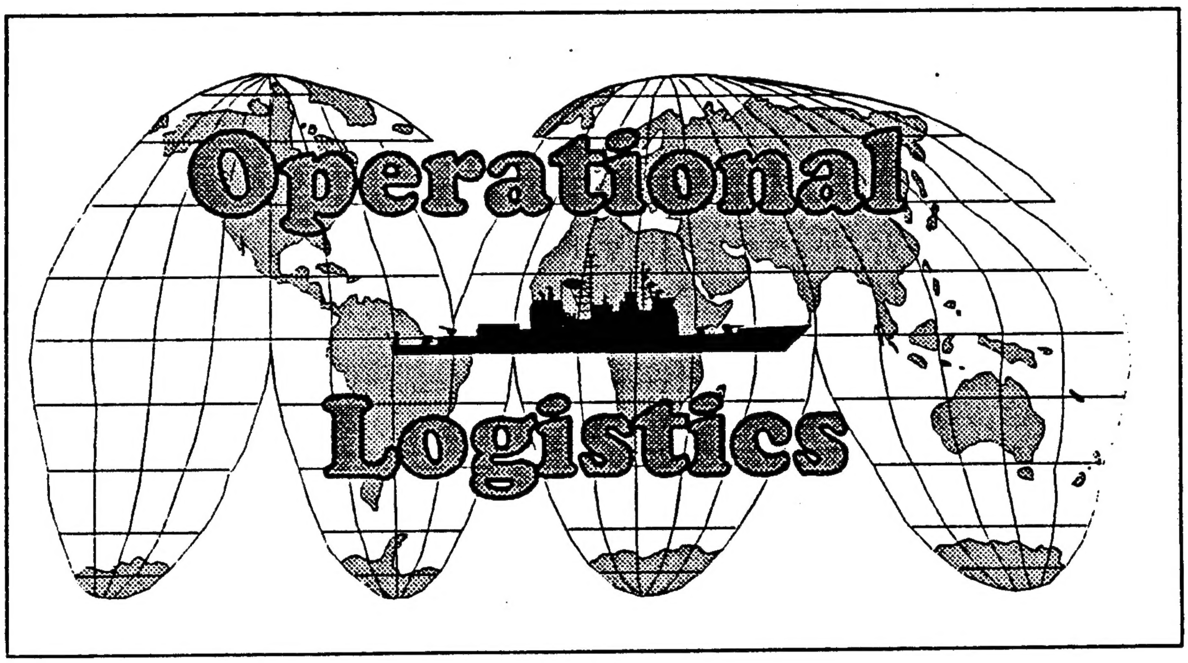
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The model places each aircraft in a hypothetical CVBG consisting of eight ships, and has it perform a set of logistics missions. The missions are based on an analysis of seven HC detachments in support of Operation Desert Storm, and consist of internal and external cargo delivery, and passenger transport.

The study concludes that for the scenario modeled, the CH-46E is a more capable combat support platform, due in large part to its larger internal cargo capacity. Further study is recommended.

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Timothy M. Wilson
Lieutenant, United States Navy
B.S., Oregon State University, 1985

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Author: Timothy M. Wilson

Approved by: Michael P. Bailey, Thesis Advisor

Thomas E. Halwachs, Second Reader

Peter Purdue, Chairman
Department of Operations Research

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This study is an operational comparison of the CH-46E and HH-60H as potential replacements for the CH-46D combat support helicopter. The comparison is performed as a simulation using the Simulated Mobility Modeling and Analysis Toolbox (SMMAT).

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The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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EXECUTIVE SUMMARY

This study is an operational comparison of the CH-46E and HH-60H as potential replacements for the CH-46D combat support helicopter. The comparison is performed as a simulation using the Simulated Mobility Modeling and Analysis Toolbox (SMMAT).

The Simulated Mobility Modeling and Analysis Toolbox (SMMAT) is a collection of objects and processes designed to facilitate the modeling of material movement along a network. SMMAT was developed over a nine month period by the author and three other students at the Naval Postgraduate School using CACI MODSIM II (1.9.1) on UNIX workstations. The purpose of the project was to provide a product that would allow students to conduct thesis research on logistics problems on a larger scale.

The model places each aircraft in a hypothetical CVBG consisting of eight ships, and has it perform a set of logistics missions. The missions are based on an analysis of seven HC detachments in support of Operation Desert Storm, and consist of internal and external cargo delivery, and passenger transport. The quantity of cargo to be moved is based on the daily average of these detachments, which is 40 tons of external cargo, 2 tons of internal cargo, 1 ton of mail, and 20 passengers. The actual amount of cargo for each run of the model is a random value within one standard deviation of the daily average.

The simulation experiment consists of 30 replications for each aircraft. Each replication begins with the aircraft empty, and terminates when the last piece of cargo has been delivered to its final destination. At the

conclusion of each replication the values for time required to complete the missions, fuel burned, number of trips, and nautical miles traveled are determined. The simulation collects the values for each replication, and determines the mean, variance, and confidence interval for each category.

Upon completion of the experiment, a statistical analysis was performed on the output data. Using a paired-differences experiment it was determined that there was a significant difference in the mean values for each performance category between the two aircraft. Having determined that there was a significant difference between the sample means, a 95% confidence interval for the mean difference (μ_d) was determined. Finally, the lower bound of the mean difference (μ_d) was determined with a 95% level of confidence.

The study concludes that for the scenario modeled, the CH-46E is a more capable combat support platform, due in large part to its larger internal cargo capacity. Further study is recommended.

I. INTRODUCTION

A. BACKGROUND

In order for the U.S. Navy to be able to operate an Aircraft Carrier Battle Group (CVBG) at sea, conducting sustained operations for indefinite periods of time, it is imperative that there be a reliable supply pipeline which provides continuous support. Additionally, in order to maximize the combat effectiveness of the CVBG, the process of resupply should interfere with tactical operations as little as possible. This support is the mission of the Combat Logistics Force (CLF). In order to carry out its mission, the CLF makes use of multi-product supply ships with embarked combat support helicopter (HC) assets, resupplying each ship in the CVBG on the order of every three days. During these underway replenishments (UNREP), fuel is transferred directly (ship-to-ship), with the majority of other products (food, ammunition, mail, spare parts, passengers, etc.) being transferred by air using helicopter vertical replenishment (VERTREP).

At this time, the Navy HC helicopter is the CH-46D. The CH-46D entered service in 1964, with a service life design limit of 10,000 flight hours. By the year 2000, most of these airframes will have exceeded this limit (O'Bannon). Additionally, the Navy Mission Need Statement (MNS) for Helicopter Combat Support Aircraft identifies a need for 123 CH-46D's (64 for fleet HC squadrons, 14 for the Fleet Readiness Squadron (FRS), 4 for Pacific Missile Test Center (PMTC) Pt. Mugu, 13 for USMC Air Station Search-and-Rescue (SAR), 8 in the maintenance pipeline, and 20 for attrition

over 20 years), yet the current inventory is less than 80 (MNS, 1992, p. 3).

From these figures, it should come as no surprise that a replacement airframe is being considered. Currently two options for CH-46D replacement are being investigated: the upgraded CH-46E, and a variant of the HH-60H.

B. PURPOSE OF STUDY

This study is intended to examine each of the two medium-lift helicopter replacement options functioning alone in the role of battle group combat support helicopter, and determine the approximate performance of each in carrying out the same set of missions. These results will then be used to determine the operational impact on the battle group combat effectiveness by examining the time it takes each platform to perform the missions, the number of trips required to move the cargo, fuel consumed, and nautical miles flown.

C. METHODOLOGY

1. The Scenario

In this scenario, a hypothetical battle group consisting of a CVN-76 class aircraft carrier, an AOE-1 class multi-product supply ship, two CG-47 class cruisers, two DDG-51 class destroyers, one DD-963 class destroyer, and one FFG-7 class frigate are to be resupplied. The AOE has a quantity of cargo to be delivered to the various ships in the battle group and the embarked HC aircraft will make the scheduled deliveries. Under the assumption that the deliveries must be scheduled in advance, the cargo will be prioritized for delivery, thereby defining a delivery route

which will not be altered. This allows each helicopter to perform essentially the same set of missions, enabling a fair comparison to be made over a common domain.

2. The Aircraft

In this simulation certain assumptions about each aircraft must be made, due to the fact that neither of these aircraft exist in the fleet in their proposed configuration at this time. However, these assumptions will be few, and because very similar platforms do exist in the fleet today, they will be based on characteristics of these existing platforms, and on the characteristics of new aircraft in general.

a. Physical Characteristics

The physical dimensions of the two proposed aircraft will be based on those currently associated with the CH-46E and HH-60H. The physical characteristics of interest here are empty weight, maximum gross weight, fuel capacity, and internal cargo space. For the CH-46E, the empty weight is 16,445 pounds, maximum gross weight is 24,300 pounds, fuel capacity is 4,488 pounds, and internal cargo space is 793 cubic feet (Hepburn, 1992, p. 102). For the HH-60H, the empty weight is 14,414 pounds, maximum gross weight is 21,884 pounds, fuel capacity is 4,412 pounds, and internal cargo space is 297 cubic feet (Hepburn, 1992, p. 110).

b. Speed and Endurance

Aircrews are reluctant to approach maximum airspeeds while operating at high gross weights, both for reasons of safety and meeting fuel management goals (dollars per flight hour). It is therefore assumed that while conducting internal cargo missions, both aircraft will

cruise at 100 KTS. For external cargo missions, because the external loads are being moved a short distance in this model, the aircraft will operate at 70 KTS. Both aircraft being proposed are either new aircraft or complete reworks, thus it is assumed that both will have new engines with similar performance characteristics, and approximately the same fuel burn rate, which for this model is 1200 pounds per hour.

c. *Reliability*

Again, because both aircraft will be considered new for the purposes of this model, no significant difference in reliability is anticipated, so breakdowns would be equally likely for either aircraft. Therefore, reliability for each aircraft will be set to 1.0 (no breakdowns), and the aircraft will be allowed to conduct the missions without interruption. This allows each aircraft to be examined strictly on what it does while it is flying. Also, maintenance inspections are not considered to be a factor.

2. The Cargo

In this model, the cargo to be moved will be based on data gathered from actual HC detachments aboard AOE/AOR class multi-product ships during Operation Desert Storm, as compiled by CAPT K. O'Bannon, N-880F6 (Appendix A). This data covers over 37 detachment months at sea, over 5,100 flight hours, with 13,025 passengers, 1,303 tons of internal cargo, 447 tons of mail, and 25,631 tons of external cargo moved. By examining the amount of various types of cargo moved, and comparing those numbers to the number of detachment fly days, an average amount of cargo per day can be estimated. From this analysis, the average cargo day is

thus defined to be 20 passengers, 2 tons of internal cargo, 1 ton of mail, and 40 tons of external cargo. This average cargo day is then used as the basis for the simulated cargo to be moved. Each of these quantities will serve as the mean of a uniform distribution, resulting in the amount of cargo of each type actually being delivered being 0.7 to 1.3 times the amount of the average cargo day.

II. THE MODEL

A. THE BATTLE GROUP

As stated in Chapter I, the battle group consists of eight ships: one aircraft carrier (CVN-76), one supply ship (AOE-1), and six escorts (2 CG-47's, 2 DDG-51's, 1 DD-963, and 1 FFG-7). In the hypothetical battle group formation, the CV is in the center of the formation, the AOE is stationed three nautical miles off the CV's starboard beam, and the escorts form a circular screen surrounding the CV at a distance of approximately 25 nautical miles (Figure 1).

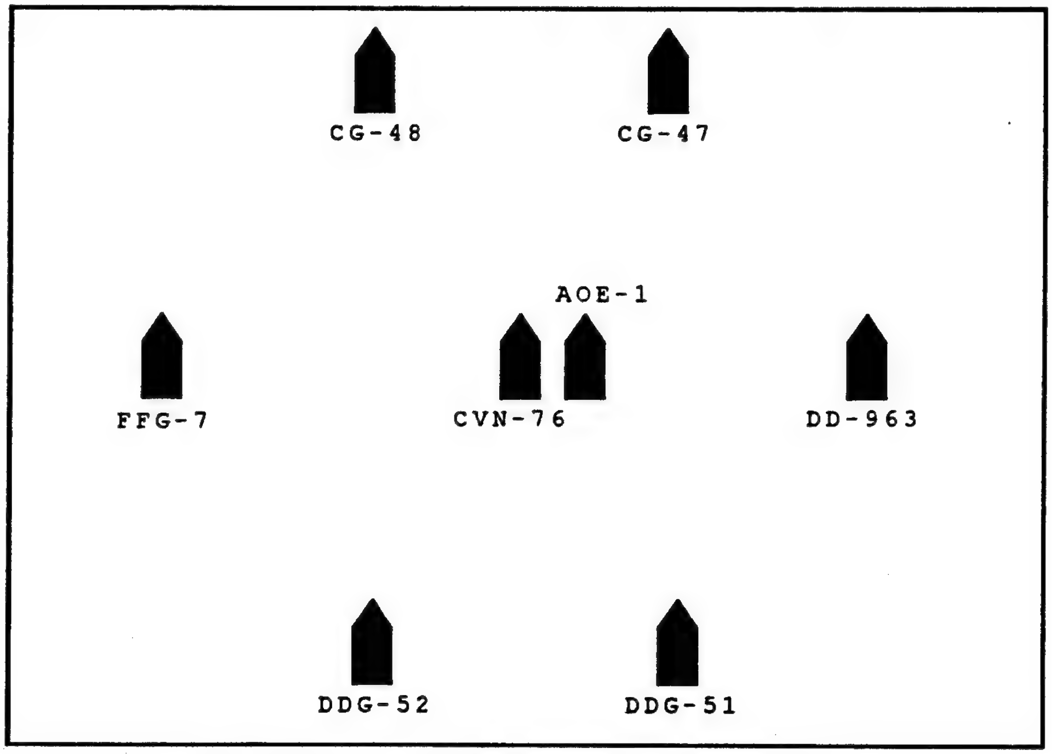

Figure 1. Battle group formation

Throughout the course of the simulation, the battle group ships never leave their relative positions. This represents a scenario in which battle group integrity is a dominant concern.

B. THE AIRCRAFT

The two aircraft being modeled are the CH-46E and the HH-60H. The physical characteristics of the two aircraft (actual and/or hypothesized) used in the model are listed in Table 1.

	CH-46E	HH-60H
Empty Weight (lbs)	16,445	14,414
Max Gross Weight (lbs)	24,300	21,884
Internal Cargo Capacity (ft^3)	793	297
Internal Cargo Airspeed (kts)	100	100
External Cargo Airspeed (kts)	70	70
Fuel Capacity (lbs)	4,488	4,412
Fuel Burn Rate (lbs/hr)	1,200	1,200

Table 1. Physical Characteristics of the Aircraft

C. THE CARGO

As stated in Chapter I, the cargo to be moved is based on the average cargo day. Since the average cargo day has been determined to be 40 tons of external cargo, 2 tons of internal cargo, 1 ton of mail, and 20 passengers, a hypothetical cargo loadout was devised, and its placement and delivery schedule arrived at.

To represent the 40 tons of external cargo, the model uses 32 pallets, each with a weight of 2,500 pounds. All of the pallets are loaded on the AOE, destined for delivery to the CV. To represent the 2 tons of internal cargo, 4 aircraft engines weighing 500 pounds each were used. Three of the four engines are being delivered from the AOE to escorts, representing replacement engines, and one of the engines is being transferred from an escort to the AOE, representing a retrograde engine. To represent the ton of mail, 204 mailbags (34 for each escort) weighing 10 pounds each are delivered, for a total of 2,040 pounds. Finally,

20 passengers were modeled and placed on various ships for transportation within the battle group.

D. EXECUTION OF THE MODEL

At the start of the simulation, the helicopter is sitting on the deck of the AOE, engines running, ready to load cargo. The actual amount of cargo at each location has been randomly set within one standard deviation of the average cargo day values, and the helicopter begins its deliveries. Prior to each transit the model checks to see if sufficient fuel is on hand to make the trip without violating minimum fuel requirements.

The delivery schedule is determined in the model by the priority assigned to the cargo. Whenever the aircraft is at a ship, if the ship has cargo that will fit aboard the aircraft, it will be loaded. Then, the next destination is determined by examining the highest priority cargo in the aircraft's cargo list and determining its destination. The priority of the cargo is as follows:

1. Pallets: AOE-1 to CVN-76.
2. Aircraft engine: AOE-1 to DD-963.
3. Mail: AOE-1 to DD-963.
4. Passengers: CVN-76 to CG-47.
5. Passengers: CVN-76 to CG-48.
6. Passengers: CVN-76 to FFG-7.
7. Aircraft engine: AOE-1 to CG-47.
8. Mail: AOE-1 to CG-47.
9. Mail: AOE-1 to CG-48.
10. Aircraft engine: AOE-1 to FFG-7.
11. Mail: AOE-1 to FFG-7.
12. Passengers: CVN-76 to DDG-52.
13. Passengers: DDG-51 to CVN-76.
14. Mail: AOE-1 to DDG-51.
15. Mail: AOE-1 to DDG-52.

16. Passengers: DDG-52 to CVN-76.
17. Passengers: CG-48 to CVN-76.
18. Passengers: CVN-76 to DDG-51.
19. Aircraft engine: DD-963 to AOE-1.

By prioritizing the cargo in this way, the relative order of delivery is set in such a way as to deliver the cargo according to a geographic plan. First, the pallets are delivered to the CV, then the mail and passengers are delivered to the escorts, working around the perimeter. The engines are interspersed in the internal cargo deliveries in order to disrupt the pattern slightly and stress the system.

In order to obtain data to be used as a basis for comparison of the two platforms, the time required, number of trips, fuel used, and nautical miles traveled are collected at the completion of each replication.

III. THE SIMULATED MOBILITY MODELING AND ANALYSIS TOOLBOX (SMMAT)

A. DESCRIPTION

The Simulated Mobility Modeling and Analysis Toolbox (SMMAT) is a collection of objects and processes designed to facilitate the modeling of material movement along a network. Designed originally to handle problems as diverse as battle group vertical replenishment, maritime pre-positioned ship offload, amphibious (LCAC) offload, and strategic sealift, it has the flexibility to handle large or small scale problems. The primary components of SMMAT are junctions, transporters, loaders, and cargo, and the functions provided to allow them to interact. The basic flow of problems using SMMAT is: loaders load cargo onto transporters, which move between junctions, until all cargo is delivered to the proper destination. Delivery can be determined by the route of the transporters, or can be determined strictly on the basis of cargo destination, with SMMAT choosing the transporter based on availability and compatibility with cargo and junction.

SMMAT provides several convenient ways to introduce variability into each problem, both during the creation of the scenario, and during the simulation itself. During the creation of the scenario, the number of pieces of cargo at each junction can be varied according to any number of statistical distributions. Additionally, any appropriate characteristic of the cargo (e.g., weight, size, volume, height) can be varied for each individual piece using the same distributions. During the execution of the simulation, additional variability is possible by using distributions for load times for each piece of cargo, as well as by introducing reliability into the loaders and transporters,

allowing them to break at random and be out of action for a variable repair time.

SMMAT also provides the capability to run replications of the scenario as specified by the user, collecting statistics on any parameter the user is interested in measuring. Upon completion of the replications, SMMAT also provides tools for statistical analysis of the total results.

B. DEVELOPMENT

The need for a product like SMMAT was conceived by Prof. Michael Bailey and Prof. William Kemple of the Naval Postgraduate School in January 1994, in order to provide a product that would allow students to conduct thesis research on logistics problems on a larger scale than previously possible. SMMAT was developed under their guidance over a nine month period by LT Tim Wilson, USN (author), CPT Don Bates, USMC, LT Ed Kearns, USN, and LT Bill Roberts, USN. SMMAT was developed using CACI MODSIM II (version 1.9.1) on UNIX workstations. SMMAT currently consists of over 50 files totaling more than five megabytes.

The development process followed a strict protocol prescribed by Prof. Bailey. First, each component had to meet the common requirements of the diverse applications being modeled by the developers. Additionally, each object and process was thoroughly tested prior to integration into the toolbox. These test programs have all been retained, and are available for modification and use by future users.

In order to create a framework allowing the creation of vastly different objects, a common data file structure was used, with special data handlers tailored to put the information contained in the data files into the proper fields of the object being created. Once a basic object has been instanciated, it inherits other attributes as is

applicable to turn it into a final object capable of performing the required functions independently.

At this time, SMMAT has been used successfully to model three scenarios (VERTREP, MPS offload, and LCAC offload). Interest in the project resulted in Prof. Bailey and the four developers being invited to present SMMAT at the 1994 CACI SummerSim Simulation Conference in Washington, D.C., August, 1994.

C. MODEL IMPLEMENTATION

1. Data Files

A critical and time consuming process in the initial implementation of a model using SMMAT is the analysis of requirements for the data files. Each of the four basic types (junction, transporter, loader, and cargo) have their own data file. In addition, a primary junction file and simulation start-up file is required. All data files must conform to a pre-defined structure in order to be processed by the data handler objects in SMMAT. Examples of the data files are provided in Appendix B.

a. Type Files

The basic type files contain static information required for each of the four types. The purpose of these files is to provide values for the fixed fields in the basic objects, or parameters used to return values for the dynamic fields in the object.

It is important to note that the structure of each specific type must contain exactly the same fields. The actual fields from each data file record used in constructing that particular object is determined at the data handler level, so the data file must contain adequate fields so that every field required by each specific type is

present. This requirement ensures that the data handler knows how many fields will be present, and reduces the risk of error.

b. Start-up Files

The start-up files are used to initialize the simulation data, and determine the actual structure of the problem. As mentioned above, the two start-up files are the simulation start-up file, and the primary junction file.

The simulation start-up file is the largest and most in-depth of all the files, containing every specific junction, transporter, loader, and piece of cargo in the simulation, as well as its location. This file is relatively simple, considering the highly flexible nature of SMMAT and the complex problems it must be able to solve, but its creation is still somewhat daunting, depending upon the complexity of the model. In this file each entry is a junction, and for each junction, everything contained at that junction must be specified. So, for each junction, the name is specified, followed by the number of transporter types, number of loader types, and number of cargo types. The complexity arises when the transporters at a junction are themselves junctions, carrying other, transporters, loaders, and cargo, and so on.

On the other hand, the primary junction file is very simple, consisting solely of names of active junctions. It was created to increase flexibility while reducing the amount of work required by the user to vary the scenario. In most cases, the junctions listed in the primary junction file will correspond exactly to the junctions listed in the simulation start-up file. This makes every junction in the simulation start-up file active. However, if the user

decides to modify the scenario to see what the loss of a particular junction would do to the system, by simply deleting it from the primary junction file it can be removed from the simulation with no editing of the more complex simulation start-up file required.

2. Data Handlers

The data handlers are used to create the initial data record and build the corresponding object. The initial data record is made by reading data from the type data files, and assigning values to the basic record. If the value to be assigned to the record is static, this operation is just a direct assignment. However, if the modeler wants to assign the value of a random sampling from a statistical distribution to the record, the information from the data file can be used a parameter for that distribution. For example, if the model was moving containers (which have a fixed size) on a container ship (which carries a fixed number of containers), the container cargo object would have fixed values for height, width, and length, but probably not for weight. Using SMMAT, the final container cargo object would then have three fixed fields (height, width, and length) with directly assigned values, and one dynamic field (weight), which is filled with a value returned from a statistical distribution determined by the modeler. After the data record is completed, the object builders build the basic object by assigning fields from the record to the corresponding fields of the object and inheriting the processes which allow the object to operate independently.

3. Basic Processes

The basic processes can be thought of as those which directly facilitate the movement of material. The basic

processes are the major capabilities of the objects, and happen automatically once the simulation starts. These are: depart junction, receive transporter, load cargo, unload cargo, and transit.

a. Depart Junction

The process of a transporter departing a junction takes place after cargo has been loaded or unloaded, and a transit is required. There are several other functions which are carried out at this time, including a time to clear the junction, a check to see if the sufficient fuel is onboard to make the transit to the destination, and refueling if necessary.

b. Receive Transporter

When a transporter arrives at a junction to load or unload cargo, a check is made to see if there is a spot available for docking. If no spot is available, the transporter is put in a queue to await docking. Once a spot is available the transporter docks, and a docking time is computed.

c. Load Cargo

A transporter loads cargo while it is docked at a junction. If the transporter requires a loader from the junction, it is given one if available. If no loader is available the transporter must wait until one is returned to the junction for reallocation. Once the loading process begins, cargo is loaded according to its priority, if it fits, and if the transporter is going where the cargo needs to go. As each piece of cargo is loaded, its individual load time is elapsed, the transporters cargo capacity is reduced by the physical characteristics of the cargo.

d. Unload Cargo

A transporter also unloads cargo while it is docked at a junction. If the transporter has cargo to unload, it will unload its cargo before loading any other cargo. As with load, the transporter may use a loader from the junction or organic assets to unload, time elapses for every piece of cargo unloaded, and transporter cargo capacity is increased as each piece of cargo is unloaded.

e. Transit

After a transporter departs a junction, it enters the transit phase. The transit process determines the course to the destination junction, and based on the designated speed of the transporter estimates a transit time. The transit phase ends when the transporter arrives at the destination junction and asks to be received.

4. Reliability

In order to more realistically model actual operations, reliability factors can be entered for any loader or transporter. If a reliability other than 1.0 is entered for a loader, that loader can randomly fail during loads or unloads. Similarly, if a reliability other than 1.0 is entered for a transporter, that transporter can randomly fail during transits. If a breakdown occurs, the affected device will be out of action for a certain amount of time for repair.

D. FUTURE REFINEMENTS

At this time, all cargo quantities are determined before the start of each simulation. However, because SMMAT is ideally suited for steady-state analyses used to stress a transportation system, a run-time cargo generator would be a natural addition to the toolbox. This would allow the user

to saturate the logistics system and determine overall throughput under a variety of dynamic conditions.

In addition, due to the unique nature of military logistics systems, especially in the area of Navy logistics, a moving waypoint structure should be added. This would allow the dynamic movement of junctions which are stationed relative to a moving object to change course, move off-station, operate for some period of time, and be able to easily return to their assigned position.

IV. MAPPING THE MODEL TO SMMAT

In order to conduct the simulation using SMMAT, the items of interest in the scenario had to be mapped to SMMAT objects. For this scenario, the items of interest to be modeled were the battle group ships, the helicopters, and the cargo. In SMMAT, the object types are junction, loader, transporter, and cargo. Once the modeler has determined which SMMAT object will be used to represent each item of interest, the data files, data handlers, and object builders must be modified to create the final SMMAT object which accurately reflects the item of interest.

1. Junctions

In this model, the junctions are the battle group ships. The sole purpose of the ships is to hold cargo waiting to be delivered, receive cargo, and dispense fuel. The ships carry out no missions, never leave their battle group position, and make no demands on the transporters. While this is certainly not realistic behavior for the ships, it is proper behavior for this model, which seeks to measure the performance of the aircraft with as little outside interference as possible.

2. Transporters

The transporters in this model are the HC helicopters, which are the objects being evaluated. The transporters are initialized with a full load of fuel and no cargo. Once the simulation begins the transporters commence loading and delivering cargo according to its priority, refueling as necessary, but never shutting down until all cargo has been delivered to its proper destination.

3. Cargo

The cargo to be moved in this model is based on the results of the analysis of the standard AOE/AOR cargo day as described earlier. The four types of cargo used were mail,

passengers, pallets (external), and parts (internal). For each cargo type, the physical characteristics of weight, size, and volume never varied, which means once the cargo was created the problem was deterministic. The variability for this model was introduced by modifying the build routines to return a random number of each cargo type at each location, within one standard deviation of the average cargo day value. This means that for each replication of the simulation, the actual amount of cargo would be based on the average cargo day, but could be as little as 0.7 or as great as 1.3 times the average value.

4. Loaders

In this model, no loaders were used. This is based on the assumption that all cargo would be loaded by deck personnel, or in the case of passengers, load itself. All external cargo would be staged prior to aircraft launch, and require only a manual hookup (cargo pendant to cargo hook) for each load. Internal cargo (mail and parts) would simply be carried aboard.

V. THE SIMULATION

A. CONDUCT OF THE SIMULATION EXPERIMENT

The simulation experiment consisted of 60 replications of the basic scenario, 30 for each aircraft. For each replication the quantity of each type of cargo at each junction was allowed to vary within one standard deviation of the average cargo day. Because the cargo quantity was variable, a number of replications was required to obtain a reasonable level of certainty that the distribution of cargo was tending toward the average cargo day. Because the simulation was run in two parts, it allowed the same seed to be used for the random number generator, thereby adding even more equality to the set of missions each aircraft would perform by providing a series of common random numbers.

The primary data of interest in comparing the two platforms was specified as the total amount of time required to complete the set of deliveries. Therefore, the simulation measured each process in the entire scenario which elapsed time, and collected the results as the total time required to complete the mission. Additionally, as a cross-reference, the number of trips required, fuel consumed, and nautical miles traveled were also measured.

At the completion of each replication, the values determined for total time, fuel burned, number of trips, and nautical miles traveled were noted for the sample, and a mean, variance, and confidence interval was computed for each of the categories. This allows the modeler to examine the value returned for the individual run, as well as the aggregate data, at the end of each replication.

B. RESULTS OF THE SIMULATION EXPERIMENT

1. CH-46E

After the series of 30 replications, the CH-46E had a mean value of 795.31 minutes for total time required, with a confidence interval width of 19.92. For fuel burned, it had a mean value of 7,152.54 pounds, with a confidence interval width of 94.04. For number of trips, it had a mean value of 33.0, with a confidence interval width of 1.76. Finally, for nautical miles traveled, it had mean value of 588.18, with a confidence interval width of 7.13 (Appendix C.).

2. HH-60H

After the series of 30 replications, the HH-60H had a mean value of 1,043.99 minutes for total time required, with a confidence interval width of 35.03. For fuel burned, it had a mean value of 10,641.38 pounds, with a confidence interval width of 343.49. For number of trips, it had a mean value of 59.73, with a confidence interval width of 4.48. Finally, for nautical miles traveled, it had mean value of 866.93, with a confidence interval width of 27.35 (Appendix D.).

3. Comparison of the Two Platforms

After comparing the numerical results of the simulation, it is readily apparent that the CH-46E outperformed the HH-60H in the in the scenario used in this model. The CH-46E took 23.8% less time, used 32.8% less fuel, made 44.8% fewer trips, and flew 32.2% fewer nautical miles than the HH-60H.

C. STATISTICAL ANALYSIS OF THE RESULTS

1. Paired-Difference Test: H_o: $\mu_d = 0$

To determine if significant differences exist between the population means, a paired-difference experiment was conducted on the two samples. In order to show with 95% certainty that no difference exists between the population

means, the experiment must return a value inside the range of $\pm t_{0.95,29} = (-2.045, 2.045)$, for a two-tailed t-test with a 95% confidence interval and 29 degrees of freedom. For time required, the t-value computed is 54.062, with a p-value of $1.1422E^{-30}$. For fuel burned, the t-value computed is 47.045, with a p-value of $6.1954E^{-29}$. For number of trips, the t-value computed is 36.9648, with a p-value of $5.9966E^{-26}$. For nautical miles traveled, the t-value computed is 46.0998, with a p-value of $1.1013E^{-29}$. As each of these values is significantly larger than $t_{0.95,29} = 2.045$, the hypothesis that there is a significant difference in the sample means can be supported with a 95% level of confidence.

2. Paired-Difference Test: 95% CI for μ_d

After having established that a difference exists between the sample means for all four categories, the next step was to determine how great a difference in the means could be expected with a 95% level of confidence.

For time required, the confidence interval for the difference between the means is (239.2780, 258.0920). For fuel burned, the confidence interval for the difference between the means is (3,337.1856, 5071.9984). For number of trips, the confidence interval for the difference between the means is (23.9651, 28.2122). For nautical miles traveled, the confidence interval for the difference between the means is (266.3875, 291.1191).

3. Paired-Difference Test: 95% Lower Bound for μ_d

The final step in the statistical analysis was to determine a lower bound for the difference in the means with a 95% level of confidence.

For time required, the lower bound of the difference between the means is 240.8696. For number of trips, the lower bound of the difference between the means is

3,362.8448. For nautical miles traveled, the lower bound of the difference between the means is 268.4797 (See Table 2).

	Time	Fuel	Trips	NMiles
$Mean_{CH\text{-}46E}$	795.31	7152.54	33.00	588.18
$Mean_{HH\text{-}60H}$	1043.99	10641.38	59.73	866.93
$Mean_{Difference}$	248.685	3488.842	26.733	278.753
95% C.I.				
Lo Bound	239.278	3337.1856	23.9651	266.3875
Hi Bound	258.092	5071.9984	28.2122	291.1191
95% Lo Bound	240.8696	3362.8448	25.5046	268.4797

Table 2. Results of Paired-Difference Experiment

D. INTERPRETATION OF THE RESULTS

While the numbers in the preceding section show a significant difference in the performance of the two aircraft, with the CH-46E outperforming the HH-60H in every category, the results must be tempered with the limitations of the model, and certain other considerations.

1. Internal Cargo Capacity

The data used to determine the average cargo day involved a great deal of internal cargo (two tons of internal cargo, one ton of mail, and 20 passengers). It is obvious from the internal cargo area specifications of the two aircraft that the CH-46E is going to dominate the HH-60H in internal cargo missions because of its much larger cargo area.

2. The Average Day

In analyzing the data to determine the average day, nowhere was there made mention as to whether the detachment involved consisted of one or two aircraft. If some of the detachments were made up of two aircraft, the average single aircraft cargo day would be proportionally smaller. This

would mean that the internal cargo and passenger capacity disadvantage faced by the HH-60H would be less pronounced.

3. Future Mission Requirements

The data used in this model came from detachments operating in support of Operation Desert Storm, which was a rigorous logistical exercise. If planners determine that most future scenarios are unlikely to face logistics challenges of that magnitude, models involving smaller cargo quantities may be more appropriate. Additionally, the hypothetical battle group used in this model consisted of eight ships. If future scenarios call for four or five ship battle groups, another model using these numbers might need to be examined.

VI. CONCLUSIONS

When considering options for a major weapon system acquisition, various analytical studies are appropriate, and should be conducted. Operational comparisons such as this one are no exception. In the specific case of choosing a replacement for the CH-46D medium-lift helicopter, this is particularly true. The unique capabilities and overall versatility of the CH-46D have helped make battle group logistics fast and efficient, and its ability to rapidly resupply in almost any wind condition has influenced the way battle group operations are conducted.

This study suggests that replacing the CH-46D with the HH-60H instead of the CH-46E could have an adverse effect on battle group operations by increasing the time it takes to perform the resupply mission. Further study with regard to this issue is highly recommended.

VII. RECOMMENDATIONS FOR FURTHER STUDY

The purpose of this model was to examine the performance characteristics of the two aircraft under consideration by having them perform the same set of missions. For this reason the quantity of cargo to be moved was fixed to within one standard deviation of the computed daily average, and delivery routes were scheduled. With little modification it would be feasible to model a long-term delivery process with highly variable cargo quantities, with or without predetermined cargo schedules.

In this model, wind envelope restrictions were removed from the scenario. It would be very relevant to modify the model to perform the set of missions with relative winds from different aspects. For example, if the battle group course is 0°, run 36 different sets of replications with the wind moving from 0° to 350° in 10° increments. This would allow the modeler to examine course and speed changes that would necessarily take place as the ships turned to provide suitable relative wind for the aircraft, additional time required for the deliveries to be made, and the amount of time ships spend out of their assigned position.

This model could also be used to examine the differences between various forms of combined UNREP operations (delivery boy, gasoline alley, service station). This would allow the analyst to examine each type of replenishment technique, and to examine how the performance of each aircraft affects overall operations in each of the different UNREP options.

The flexibility of SMMAT provides the modeler many options for analysis once the data files are prepared and

the objects are instanciated. Because the objects are independent entities throughout the life of the simulation, their manipulation is limited only by the user. The above variants to the existing model are a only a few of the possibilities that have occurred to the author, but certainly many other scenarios could be based on this model.

APPENDIX A. HC DETACHMENT DATA

Sq/Det	CLF	Months	Pax (#)	Int (T)	Mail (T)	Ext (T)	Flt Hr	Flt Days
HC-8/2	AOE-4	7.61	2540	312	152	6753	1000.6	125.1
HC-8/3	AOE-3	7.27	3751	293	122	4857	1095.5	136.9
HC-8/6	AOR-2	8.29	2086	109	46	4311	975.9	122.0
HC-8/5	AOR-4	6.13	1947	315	69	2955	752.4	94.1
HC-8/1	AOR-6	4.77	1462	135	21	1991	540.7	67.6
HC-8/3	AOE-3	0.87	333	66	4	2490	190.3	23.8
HC-6/5	AOR-6	3.00	906	73	33	2274	544.8	68.1
TOTAL		37.94	13025	1303	447	25631	5100.2	637.5
AVERAGE DAY			**20**	**2**	**1**	**40**	**8**	

APPENDIX B. SMMAT DATA FILES

```
#  cargo.dat
#  This is the cargo "type" fixed data file

4  #  Number of records

Pallet ->
2500         #  Weight
16           #  Volume
0            #  NumberPax
1            #  NumberPallets
1            #  LoadTime
TRUE         #  ExternalLoad
\\

Mail ->
10           #  Weight
6            #  Volume
0            #  NumberPax
0            #  NumberPallets
0.5          #  LoadTime
FALSE #  ExternalLoad
\\

Passenger ->
200          #  Weight
15           #  Volume
1            #  NumberPax
0            #  NumberPallets
1            #  LoadTime
FALSE #  ExternalLoad
\\

Passenger ->
500          #  Weight
96           #  Volume
1            #  NumberPax
0            #  NumberPallets
5            #  LoadTime
FALSE #  ExternalLoad
\\

#  EOF cargo.dat
```

```
#  junction.dat
#  This is the junction data file, names should agree with pjname.dat

8  #  Number of records

CVN76 ->
CVN76          #  Name
0              #  XCoordinate
0              #  YCoordinate
1              #  NumSpots
\\

AOE1 ->
AOE1           #  Name
3              #  XCoordinate
0              #  YCoordinate
1              #  NumSpots
\\

CG47 ->
CG47           #  Name
10             #  XCoordinate
25             #  YCoordinate
1              #  NumSpots
\\

CG48 ->
CG48           #  Name
-10            #  XCoordinate
25             #  YCoordinate
1              #  NumSpots
\\

DD963 ->
DD963          #  Name
25             #  XCoordinate
0              #  YCoordinate
1              #  NumSpots
\\

FFG7 ->
FFG7           #  Name
-25            #  XCoordinate
0              #  YCoordinate
1              #  NumSpots
\\
```

```
DDG51 ->
DDG51         #  Name
10            #  XCoordinate
-25           #  YCoordinate
1             #  NumSpots
\\

DDG52 ->
DDG52         #  Name
-10           #  XCoordinate
-25           #  YCoordinate
1             #  NumSpots
\\

#  EOF junction.dat
```

```
#  trans.dat
#  This is the transporter "type" fixed data file

2  #  Number of records

H46 ->
16445       #  EmptyWeight
24300       #  MaxGrossWeight
793         #  Volume
24          #  NumberPax
5           #  NumberPallets
2.5         #  NESpeed
4488        #  MaxFuel
400         #  MinFuel
20          #  BurnRate
1.67        #  IntSpeed
1.17        #  ExtSpeed
\\

H60 ->
14414       #  EmptyWeight
21884       #  MaxGrossWeight
297         #  Volume
8           #  NumberPax
2           #  NumberPallets
3.0         #  NESpeed
4412        #  MaxFuel
400         #  MinFuel
20          #  BurnRate
1.67        #  IntSpeed
1.17        #  ExtSpeed
\\

#  EOF trans.dat
```

```
#  pjname.dat
#  This is the master junction data file

1  #  Number of records

Master ->
CVN76        #  Junction CVN-76
AOE1         #  Junction AOE-1
CG47         #  Junction CG-47
CG48         #  Junction CG-48
DD963        #  Junction DD-963
FFG7         #  Junction FFG-7
DDG51        #  Junction DDG-51
DDG52        #  Junction DDG-52
\\

#  EOF pjname.dat
```

```
#  simstart.dat
#  This is the DYNAMIC data file

9  #  Number of records

CVN76 ->
5      #  Number of cargo types
0      #  Number of transporter types
0      #  Number of loader types

# *** Cargo List ***

Passenger
  1
    CG47Pax          #  Name
    4                #  Priority
    2                #  Quantity
    2                #  Number in junction path
    CVN76            #  Origination junction
    CG47             #  Destination junction

Passenger
  1
    CG48Pax          #  Name
    5                #  Priority
    4                #  Quantity
    2                #  Number in junction path
    CVN76            #  Origination junction
    CG48             #  Destination junction

Passenger
  1
    FFG7Pax          #  Name
    6                #  Priority
    2                #  Quantity
    2                #  Number in junction path
    CVN76            #  Origination junction
    FFG7             #  Destination junction

Passenger
  1
    DDG51Pax         #  Name
    18               #  Priority
    2                #  Quantity
    2                #  Number in junction path
    CVN76            #  Origination junction
    DDG51            #  Destination junction

Passenger
  1
    DDG52Pax         #  Name
    12               #  Priority
    2                #  Quantity
    2                #  Number in junction path
    CVN76            #  Origination junction
    DDG52            #  Destination junction
```

```
# *** Transporter List ***

# *** Loader List ***

\\  #  EOR CVN76

AOE1 ->
10    #  Number of cargo types
1     #  Number of transporter types
0     #  Number of loader types

# *** Cargo List ***

  Pallet
  1
    CVN76Pallet     #  Name
    1               #  Priority
    32              #  Quantity
    2               #  Number in junction path
    AOE1            #  Origination junction
    CVN76           #  Destination junction

Mail
  1
    CG47Mail        #  Name
    8               #  Priority
    34              #  Quantity
    2               #  Number in junction path
    AOE1            #  Origination junction
    CG47            #  Destination junction

Mail
  1
    CG48Mail        #  Name
    9               #  Priority
    34              #  Quantity
    2               #  Number in junction path
    AOE1            #  Origination junction
    CG48            #  Destination junction

Mail
  1
    DD963Mail       #  Name
    3               #  Priority
    34              #  Quantity
    2               #  Number in junction path
    AOE1            #  Origination junction
    DD963           #  Destination junction

Mail
  1
    FFG7Mail        #  Name
    11              #  Priority
    34              #  Quantity
    2               #  Number in junction path
    AOE1            #  Origination junction
```

```
    FFG7            #  Destination junction Mail
  1
    DDG51Mail       #  Name
    14              #  Priority
    34              #  Quantity
    2               #  Number in junction path
    AOE1            #  Origination junction
    DDG51           #  Destination junction

Mail
  1
    DDG52Mail       #  Name
    15              #  Priority
    34              #  Quantity
    2               #  Number in junction path
    AOE1            #  Origination junction
    DDG52           #  Destination junction

Engine
  1
    DDG963Engine    #  Name
    2               #  Priority
    1               #  Quantity
    2               #  Number in junction path
    AOE1            #  Origination junction
    DD963           #  Destination junction

Engine
  1
    CG47Engine      #  Name
    7               #  Priority
    1               #  Quantity
    2               #  Number in junction path
    AOE1            #  Origination junction
    CG47            #  Destination junction

Engine
  1
    FFG7Engine      #  Name
    2               #  Priority
    1               #  Quantity
    2               #  Number in junction path
    AOE1            #  Origination junction
    FFG7            #  Destination junction
```

```
# *** Transporter List ***

H46
1
  H46              #  Name
  3 0              #  Xcoord YCoord
  0                #  Number in LegalDestA
  8                #  Number in LegalDestB
    CVN76          #  Legal Destinations
    AOE1           #
    CG47           #
    CG48           #
    DD963          #
    FFG7           #
    DDG51          #
    DDG52          #
  AOE1             #  Origination Junction

#H60
#1
#  H60                  #  Name
#  3 0                  #  Xcoord YCoord
#  0               #  Number in LegalDestA
#  8               #  Number in LegalDestB
#    CVN76         #  Legal Destinations
#    AOE1          #
#    CG47          #
#    CG48          #
#    DD963         #
#    FFG7          #
#    DDG51         #
#    DDG52         #
#  AOE1            #  Origination Junction

# *** Loader List ***

\\  #  EOR AOE1

CG47 ->
0      #  Number of cargo types
0      #  Number of transporter types
0      #  Number of loader types

# *** Cargo List ***

# *** Transporter List ***

# *** Loader List ***

\\  EOR CG47

CG48 ->
1      #  Number of cargo types
0      #  Number of transporter types
0      #  Number of loader types
```

```
# *** Cargo List ***

Passenger
  1
    CVN76Pax2      #  Name
    17             #  Priority
    4              #  Quantity
    2              #  Number in junction path
    CG48           #  Origination junction
    CVN76          #  Destination junction

# *** Transporter List ***

# *** Loader List ***

\\  EOR CG48

DD963 ->
1      #  Number of cargo types
0      #  Number of transporter types
0      #  Number of loader types

# *** Cargo List ***

Engine
  1
    DD963Engine    #  Name
    99             #  Priority
    1              #  Quantity
    2              #  Number in junction path
    DD963          #  Origination junction
    AOE1           #  Destination junction

# *** Transporter List ***

# *** Loader List ***

\\  EOR DD963

FFG7 ->
0      #  Number of cargo types
0      #  Number of transporter types
0      #  Number of loader types

# *** Cargo List ***

# *** Transporter List ***

# *** Loader List ***

\\  EOR FFG7

DDG51 ->
0      #  Number of cargo types
0      #  Number of transporter types
0      #  Number of loader types
```

```
# *** Cargo List ***

Passenger
  1
    DDG52Pax        #  Name
    16              #  Priority
    2               #  Quantity
    2               #  Number in junction path
    DDG52           #  Origination junction
    CVN76           #  Destination junction

# *** Transporter List ***

# *** Loader List ***

\\  EOR DDG51

DDG52 ->
0     #  Number of cargo types
0     #  Number of transporter types
0     #  Number of loader types

# *** Cargo List ***

# *** Transporter List ***

# *** Loader List ***

\\  EOR DDG52

H46 ->
0     #  Number of cargo types
0     #  Number of transporter types
0     #  Number of loader types
\\  #  EOR H46

#H60 ->
#0    #  Number of cargo types
#0    #  Number of transporter types
#0    #  Number of loader types
#\\  #  EOR H60

\\  #  EOF simstart.dat
```

APPENDIX C. CH-46E OUTPUT

CH-46E			
Time	**Fuel**	**Trips**	**NMiles**
815.72	7261.66	35	596.09
829.43	7348.87	37	602.09
823.72	7261.66	35	596.09
804.01	7174.45	33	590.09
830.16	7310.49	35	600.17
826.72	7261.66	35	596.09
773.04	7048.86	29	582.17
820.16	7310.49	35	600.17
738.59	7000.03	29	578.09
799.01	7174.45	33	590.09
811.72	7261.66	35	596.09
765.59	7000.03	29	578.09
837.72	7261.66	35	596.09
759.59	7000.03	29	578.09
792.30	7087.24	31	584.09
816.72	7261.66	35	596.09
839.16	7310.49	35	600.17
781.01	7174.45	33	590.09
759.45	6823.16	32	560.76
793.78	7135.90	36	584.31
814.01	7174.45	33	590.09
802.01	7174.45	33	590.09
739.65	6874.27	30	566.31
772.30	7087.24	31	584.09
777.04	7048.86	29	582.17
795.01	7174.45	33	590.09
771.30	7087.24	31	584.09
799.01	7174.01	33	590.09
795.72	7261.66	35	596.09
775.52	7050.67	36	577.19
Totals			
23859.17	214576.20	990.00	17645.31
Mean Values			
795.31	7152.54	33.00	588.18

APPENDIX D. HH-60H OUTPUT

HH-60H			
Time	**Fuel**	**Trips**	**NMiles**
1073.96	10792.84	66	875.56
1124.46	11568.68	69	939.06
1118.76	11481.47	67	933.06
1047.56	10518.91	61	855.25
1109.34	11360.14	63	925.49
1115.44	11394.26	65	927.06
991.81	10143.99	50	831.64
1071.03	10754.46	64	873.64
943.22	9808.05	50	802.31
1065.65	10972.33	61	894.39
1087.07	11146.75	65	906.39
971.94	9879.63	50	809.56
1104.11	10980.80	65	892.54
992.73	10449.07	49	858.39
1034.15	10623.49	53	870.39
1077.82	10845.93	66	879.99
1093.62	10840.28	64	880.80
1014.56	10457.71	57	852.71
998.32	10156.89	58	826.31
1043.78	10480.30	67	848.18
1071.69	10806.38	61	880.54
1038.33	10497.09	58	855.99
968.30	10035.56	54	818.74
982.12	10016.42	52	819.70
1022.73	10749.67	49	883.50
1061.65	10972.33	61	894.39
1030.57	10797.91	57	882.39
1033.56	10365.26	60	843.70
1008.59	9951.99	64	805.35
1022.85	10392.87	66	840.88
Totals			
31319.72	319241.46	1792.00	26007.90
Mean Values			
1043.99	10641.38	59.73	866.93

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